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CONTENT

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AUTOMATED PROCESSING LINE FOR EFFICIENT SORTING OF WASTE RECYCLABLE MATERIALS

TODOR CHEKEROVSKI, DALIBOR SERAFIMOVSKI, ANA EFTIMOVA AND FILIP STOJCHEVSKI

Abstract. This paper is considering the implementation of a modern automated processing line designed to enhance the efficiency of waste material sorting. With a focus on delivering products of optimal quality and quantity within defined timeframes, the research uses a comprehensive methodology integrating advanced automation techniques. Through an examination of the complex dynamics inherent in sorting processes, the research not only addresses fundamental challenges in waste management understanding but also highlights positive environmental outcomes and promotes ecological integrity. The integration of automated systems aims both to improve productivity and staff working conditions and to align with the imperative of promoting a more ecologically sustainable environment. The architectural layout of the facility is strategically organized into two specialized zones, including the reception area for waste intake and sorting and the preprocessing section utilizing advanced technologies. These identified zones collectively form the backbone of the facility's infrastructure, ensuring a systematic and effective approach to waste management.

1. Introduction

With the rapidly growing industrialization and the increase in consumption, driven by the population growth and modern lifestyles, the challenges related to waste management have become a serious initiative of contemporary societies. Irresponsible disposal of waste materials is a global environmental problem with a significant impact on the environment and human health. The consequence of such irresponsible actions are climate changes on a global scale, environmental disasters, and unfavourable conditions for living and survival. Recycling is a basic approach when dealing with environmental challenges. Through systematic collection, sorting, processing, and reusing materials, recycling significantly reduces the negative impacts of pollution on the environment. Previously, workers in recycling facilities were responsible for waste sorting tasks. Due to the nature of these tasks, manual sorting is characterized as an outdated and difficult process, and the shortage of labour in this sector is particularly pronounced. Today, robotic automation is replacing human labour in this field, significantly increasing the efficiency of the entire waste sorting process. With the ability to process larger waste quantities, there is an opportunity to increase the volume of recycled materials. This has a positive impact on preserving resources and reducing waste that ends up in landfills. Accepting the recycling practices is not only an act of responsibility towards nature, but also an initiative to promote sustainable solutions that improve the global environmental standard.

Date: March 27, 2024.
Keywords. Robotic automation, waste management, sorting, RVM, deep learning, artificial intelligence

2. **Facility Overview: Main Features and Phases**

The facility constitutes an automated infrastructure that, utilizing contemporary technological innovations, enables monitoring and control of a continuous operation of sorting recyclable waste materials. In addition to its advanced automation capabilities, the facility includes several key features that optimize the sorting process. These include modern sorting systems for efficient material separation, ensuring high – quality output. The facility also prioritizes sustainability, implementing eco-friendly practices to minimize environmental impact and to promote responsible waste management. The dynamics of the entire process can be divided into two main phases:

- Waste collection;
- Waste sorting.

Recycling of a material would produce a brand-new supply of the same material – for example, a used plastic bottle would be converted into a new plastic bottle. However, achieving this is often challenging or too expensive (compared with producing the same product from raw materials or other sources) due to the fact that the waste is not pre-sorted, leading to the possibility of encountering a mixture of materials within a single product. Therefore, the active participation of the community in the initial phase of the process is essential.

3. **Waste collection**

The process begins with the crucial task of waste collection and sorting. In this phase, active participation of individuals who dispose their waste properly is very important. Reverse Vending Machine, often known simply as RVM, is an effective approach to involve the community in the waste management. RVM is a famous paid recycling method in Europe and the United States [4]. It is designed to encourage recycling habits by rewarding depositors with refund for each recycled item. The operation of such machine is as simple as that of an ATM machine [5]. The RVM incorporates user-friendly features such as clear instructions and intuitive interfaces, ensuring simple operation for individuals of all ages. Equipped with an opening to receive cartons, plastic (PET), cans and glass, users can effortlessly insert their items into the designated slot. A reverse vending machine has to be able to recognize the beverage container material and correctly refund the deposit [3]. As shown in figure 1, certain items are not suitable for recycling with RVM, because they are too large to fit through the machine's opening or because they contain additional material of a different type.

Figure 1. *RVM compatible and incompatible items*[1]

[1] https://returnandearn.org.au/how-it-works/containers/

The operation is straightforward. Depositors enter their unique PIN. If the PIN is correct, they can insert their items. When a container is inserted, images are captured by cameras installed within the RVM. Using the deep learning method, the machine evaluates if the item meets the criteria for recycling. Accepted items enable depositors to earn rewards. Otherwise, if the item does not meet the criteria for recycling, it is immediately returned to the user. The deep learning model combines advanced image recognition algorithms to identify specific features of each item. This includes analysing textures, shapes, and colour patterns, allowing more accurate categorization. The process diagram illustrating the operation of the RVM is presented in Figure 2.

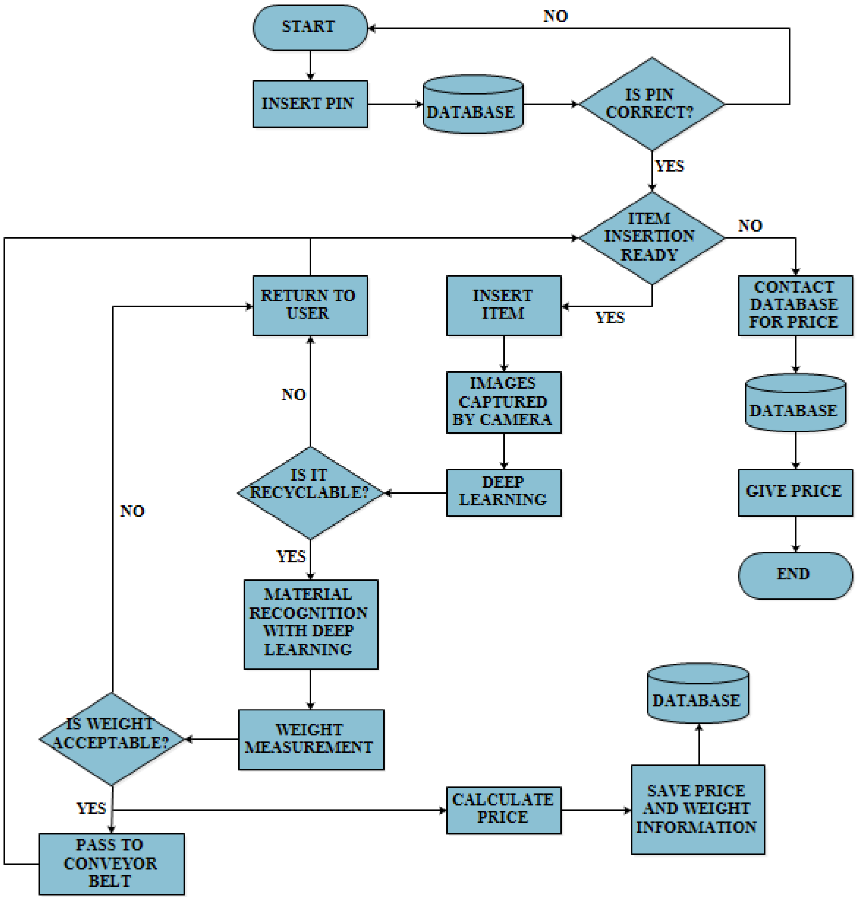

Figure 2. *Process diagram of RVM*

For precise material identification and refund processing, the system relies on sophisticated deep learning method. The images captured of the inserted item are used to determine its size (length and width). Based on the size, an item is categorised as small, medium, or large. Additionally, to minimize the risk of tricking the machine, weight measurement is also implemented to detect any potential presence of liquids or heavy foreign objects within the item. Each class is associated with specific weight ranges, which vary depending on the type of material. Refunds are provided only if the deep learning model successfully identifies the inserted item and if its weight is below the defined maximum value for the particular material. With this, the task of the citizens is responsibly completed, and the rest is left to the sorting plant.

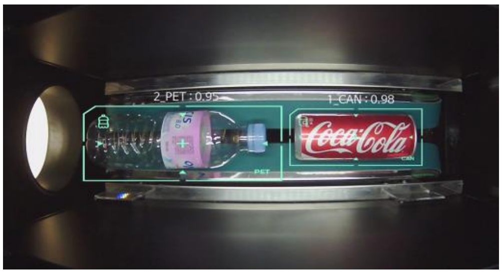

Figure 3. *Deep learning method of RVM*[2]

4. **Waste sorting**

Once considered suitable, the items are passed onto a conveyor belt system integrated within each RVM. These conveyor belts serve as a gateway to the facility beyond the RVM's exterior. Conveyor belts from all RVMs are linked to a central belt, where robotic manipulators are stationed for efficient material sorting. An industrial robot's movements are coordinated by a predefined program, executed by a controller. The controller activates the joint actuators as needed, while receiving feedback signals from the joint sensors. Robotic manipulators, engaged in sorting activities, operate under continuous path control. These robots have the ability to navigate paths of any configuration while dynamically modifying their speed throughout the arm's movement. The robot adjusts its movements in real-time to maintain continuous response to sensory inputs. The conveyor's speed must be adjusted accordingly to enable the robots, with continuous path control capabilities, to detect and pick the containers within its designated zone called tracking window. This area serves as a defined space within which the robot focuses its attention and performs specific actions.

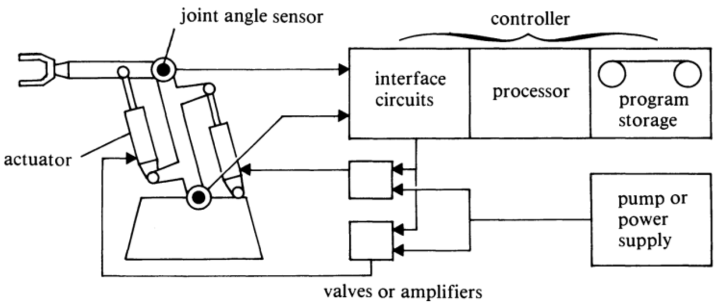

Figure 4. *The basic architecture of an industrial robot, Adopted from [1]*

[2] https://www.aitimes.com/news/articleView.html?idxno=138981

Robotic vision system has a vital role in waste sorting operations, enabling robots to perceive their environment. Some applications of vision in robotics are listed below: [1]

- Detecting object presence;
- Material identification;
- Determining object location and orientation;
- Shape and size determination;
- Monitoring;
- Quality inspection.

Vision systems are occasionally supplied by the robot's manufacturer and integrated with the controller, but usually are separate, with an interface to the controller [1]. Figure 5 presents the basic organization of a robot's vision system.

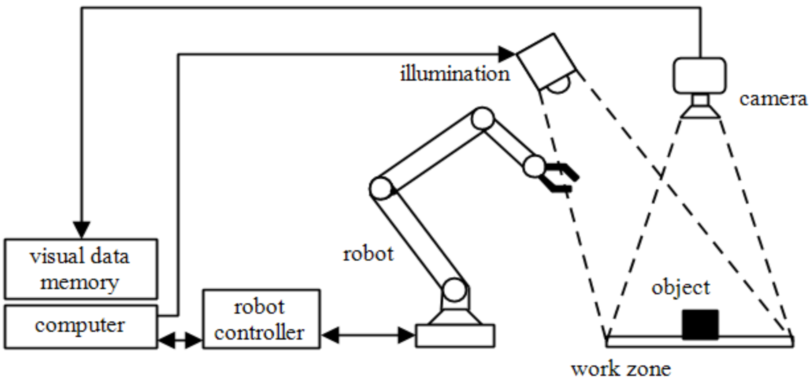

Figure 5. *Robot's vision system*

The vision system includes cameras that capture footage of the objects on the operational area of the conveyor belt. Visual data will be captured at a specified distance from the robot's arm, ensuring that the machine has enough time to analyse the data and determine the robot's behaviour. Proper illumination can significantly improve the ability of the vision system to distinguish objects from their backgrounds. Visual data memory is used for saving digital images. Once they are in the memory, they can be read by a computer. The visual data collected from the camera is relayed from the computer to the controller operating the robotic arm.

Before the integration of AI, robotics primarily relied on pre-programmed instructions for executing tasks. Currently, artificial intelligence-based methods form the foundation of all computer vision systems. AI-driven sorting systems use machine learning algorithms to identify and separate different types of waste materials with astonishing accuracy and speed [9][3]. These systems employ a combination of sensors, cameras, and robotics to analyse and categorize waste, ensuring that recyclables are efficiently sorted,

[3] https://www.linkedin.com/pulse/innovations-waste-management-paving-way-sustainable-future-jaworski-aynae/?trk=article-ssr-frontend-pulse_more-articles_related-content-card

reducing contamination, and increasing the overall rate of recycling [9][4]. Robots for sorting waste materials are undergoing remarkable evolution, thanks to the integration of advanced technologies. This includes utilization of sophisticated features like multi-sensor scanning and real-time AI analysis. Figure 5 illustrates the fundamental control principle of the industrial robot's software, incorporating artificial intelligence implemented using cloud-based systems.

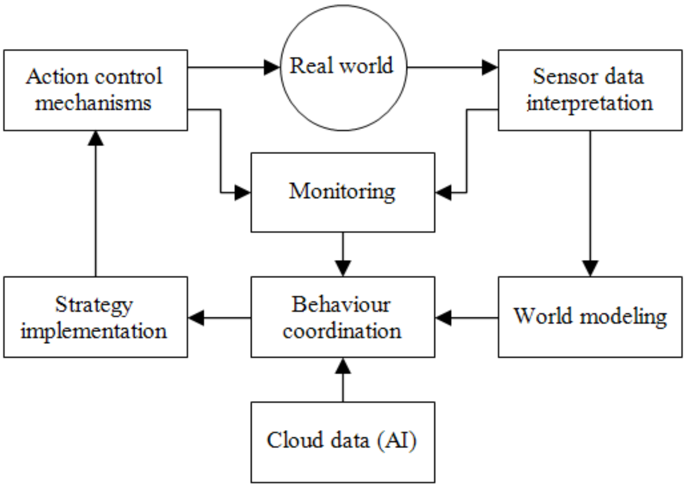

Figure 5. *Control structure of an industrial robot*

What makes AI a remarkable innovation is its adaptability and learning capability. Over time, these systems become more precise and capable of identifying a broader spectrum of materials. Training a deep learning model can take a lot of time and resources [2]. Furthermore, it also requires a lot of labelled data [2]. This step is fundamental for several reasons. A varied dataset should encompass a wide range of objects, scenes, backgrounds, lighting conditions, angles, and variations. This representation mirrors the complexity and diversity found in real-world visual data, enabling the model to learn effectively from different scenarios. Exposure to diverse images during training enhances the model's adaptability. Training on a diverse dataset enables the model to adapt its knowledge and apply it to new images that are not part of the training set, resulting in improved and more reliable performance in real-world applications. In addition, the adaptive nature of AI training allows ongoing optimization, where feedback loops enable the model to adapt and improve its performance based on real-world interactions and outcomes.

Sorting is done in separate bins attached to each robot. The purpose of a robotic arm is to carry a workpiece. One common approach is to use a gripper which, like the human hand, is adaptable to the object being lifted. Many objects can be grasped well by a hand with two or more fingers with extra joints. The gripper is rubberized, making it suitable

[4] https://www.linkedin.com/pulse/innovations-waste-management-paving-way-sustainable-future-jaworski-aynae/?trk=article-ssr-frontend-pulse_more-articles_related-content-card

for picking up delicate objects, such as glass bottles. In addition to the gripper's adaptability, advanced robotic arms are equipped with sensors and actuators that enable precise control and manipulation with objects during the sorting process. These sensors provide feedback on grip strength, object orientation and surface texture, allowing the robotic arm to adjust its grip and handling technique accordingly. Furthermore, the integration of deep learning algorithms improves the robotic arm's efficiency over time, as it learns to anticipate and adapt to variations in object size, weight, and shape.

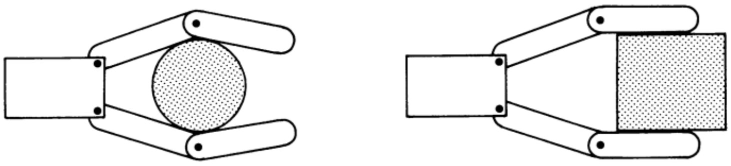

Figure 6. *Adapting gripper with two joined fingers, Adopted from [1]*

Touch sensing between the jaws of the gripper is used to detect pressure or contact with the object being handled, allowing precise control over the gripping action. In the case of object-to-gripper touch, the crudest kind of sensing is the detection of contact and can be done by a microswitch [1]. Another approach is determining the size of the object by measuring the separation between the gripper jaws. This requires sensors for jaw position [1]. Touch sensors can be organized in a square array for an indication of the object's shape and position within the gripper jaws. Each element within the array may consist of a basic contact sensor or a more sophisticated force or displacement transducer.

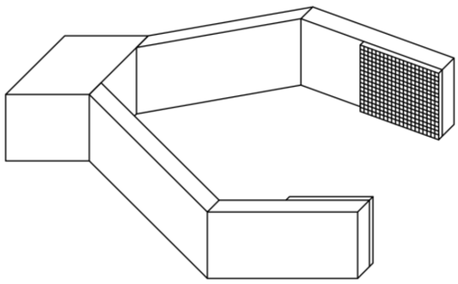

Figure 7. *Touch sensing*

Suction cups or vacuum grippers are widely used in waste sorting. Gripping a smooth, flat item using suction is an easy task, but handling objects with rough surfaces or complex shapes can be a challenge. To overcome this, the advanced vacuum grippers are equipped with adjustable suction strength capabilities, enabling them to adapt to the specific requirements of different materials and weights. The main difference between hand and vacuum grippers is their load capacity. Vacuum grippers have limited load capacity because of the suction strength and the surface area in contact with the gripper.

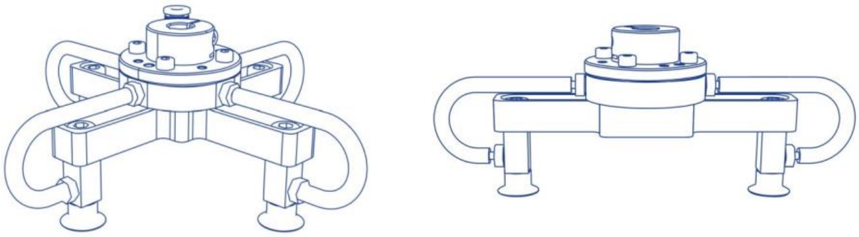

Figure 8. *Vacuum grippers*[5]

Sorting robots are able to load, transport and sort, replacing workers in the processing of materials [10][6]. Upon the item's material recognition, the robotic manipulator carries it to the suitable bin assigned for the specific material type (glass, plastic, cartons, and cans). This marks the conclusion of this phase, ensuring that the materials are appropriately categorised and ready for further processing stages. After the precise categorization process, each type of waste undergoes additional preparation to maximize its recycling potential. This includes actions such as compacting plastic bottles, shredding cartons and crushing aluminium cans. These measures not only optimize the use of available space, but they also simplify the handling and transportation to the recycling centre.

5. Conclusion

Automated robotic sorting represents the biggest achievement in contemporary waste management practices. Technological innovations, driven by the urgency to protect the environment, are fundamentally transforming the approach to waste handling. Investing in research and development for better waste sorting techniques is important to continuously improve the efficiency of the system. With automated waste management, significant reduction of environmental harm can be achieved, while maximizing resource recovery. The integration of advanced robotics ensures more precise sorting and processing of materials, leading to higher recycling rates and less waste sent to landfills.

[5] https://www.muzix.eu/bg/DOBOT/Robotic/DBT-MAG-PRO-SCK/DOBOT-MG400-SUCTION-CUP-KIT-Suction-Cup-Kit-for-Magician-MG400-PRO-Robot-Arms

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Todor Chekerovski
University "Goce Delcev", Stip
Faculty of Electrical Engineering
R. N. Macedonia
Email: todor.cekerovski@ugd.edu.mk

Dalibor Serafimovski
University "Goce Delcev", Stip
Faculty of Electrical Engineering
R. N. Macedonia
Email: dalibor.serafimovski@ugd.edu.mk

Ana Eftimova
University "Goce Delcev", Stip
Faculty of Electrical Engineering
R. N. Macedonia
Email: ana.20668@student.ugd.edu.mk

Filip Stojchevski
University "Goce Delcev", Stip
Faculty of Electrical Engineering
R. N. Macedonia
Email: filip.20677@student.ugd.edu.mk